^{10}Be FROM THE ACTIVE SUN. K. Nishiizumi[1], M. W. Caffee[2] and J. R. Arnold[3], [1]Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450 (kuni@ssl.berkeley.edu), [2]Institute of Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, Livermore, CA 94550, [3]Department of Chemistry, University of California, San Diego, La Jolla, CA 92093-0524.

Gamma-ray measurements indicate nuclear interactions occur in various depths of the solar atmosphere [1]. Such nuclear interactions can produce ^{10}Be (half-life = 1.5x10^6 year) in the active regions of the Sun by either accelerated protons bombarding ambient gas or accelerated higher Z nuclei bombarding ambient hydrogen gas. The predominant targets for the production of ^{10}Be are C, N, and O. However, the production rates in the solar atmosphere are not known. Some of this ^{10}Be escapes from the Sun, most likely incorporated in the solar wind (SW) or solar energetic particles (SEP). The abundances of ^{10}Be, or other long-lived radionuclides, in the SW and SEP are not known. A small fraction of the ^{10}Be intersects the Moon and is implanted in lunar surface materials. Accordingly, we predicted that the ^{10}Be from the Sun could be detected in the surfaces of lunar soil grains.

The detection of SW- or SEP-associated ^{10}Be on the surface of the Moon has the advantage over that of ^{14}C, ^{26}Al, or ^{36}Cl because the production rate of ^{10}Be by solar cosmic rays (SCR) in lunar surface materials is nearly negligible [2]. On the other hand, appreciable amounts of ^{14}C, ^{26}Al, or ^{36}Cl are produced by SCR on the lunar surface that will mask the expected small amount of these nuclides from the Sun. The only significant target element for ^{10}Be production by SCR in lunar samples is O. Furthermore, because of its relatively longer half-life, solar-derived ^{10}Be will be accumulated both exactly on the lunar surface, where it is implanted, and also to a cm depth, as a result of gardening on a million-year time scale. The successful detection of solar-implanted ^{10}Be hinges critically on its separation from lunar *in-situ* produced ^{10}Be. The separation of these two components will be accomplished utilizing acid leaching of the mineral grains.

Two Apollo 17 trench soils, 78481 (0-1 cm depth) and 78421 (bottom layer of a 25 cm deep trench), were selected for this test experiment. The soil samples were separated into 30-65 μm, 65-130 μm, and >130 μm diameter fractions. Each sample (150-200 mg) was subsequently leached by different concentrations of acid solution, 0.02 mmol HNO_3, 0.5 mmol HNO_3+0.002 mmol HF, 1 mmol HNO_3+0.02 mmol HF, and 1 mmol HNO_3+0.2 mmol HF, in an ultrasonic bath and was totally dissolved by an HF+HNO_3 mixture. Be, Al, and Cl were separated from each fraction, and ^{10}Be, ^{26}Al, and ^{36}Cl concentrations were measured using accelerator mass spectrometry at LLNL-AMS facility [3]. Concentrations of Mg, Al, Ca, and Fe in aliquots of leachant were measured by atomic absorption spectroscopy.

The ^{10}Be, ^{26}Al, and ^{36}Cl concentrations in each fraction varied by three to four orders of magnitude since different amounts of surface layers were dissolved. Fig. 1 shows ^{10}Be, ^{26}Al, and ^{36}Cl concentrations in each leached fraction normalized to the dissolved Mg, Al, Ca, and Fe (dpm/kg Mg+Al+Ca+Fe). All cosmogenic nuclides in the deeper sample (78421) were produced *in-situ* by galactic cosmic rays (GCR). Higher concentrations of ^{26}Al and ^{36}Cl in the surface sample (78481) indicate the *in-situ* SCR production of these nuclides in addition to GCR production. Because the total dissolution sample was obtained after sequential leaching steps, it contains only *in-situ* cosmogenic nuclides.

The normalized ratio of the concentration of a nuclide in each fraction of the surface sample to that of the deep sample is shown in Fig. 2. In order to eliminate the effects of different SCR and GCR production as a function of depth, the ratio was calculated after a further normalization in which the cosmogenic nuclide concentration in the total dissolution of each sample was set to unity.

The result of this first experiment indicates that the most dilute HF (0.002 mmol), which removes the outermost layer of the grains, leached 30-40 % more ^{10}Be in the surface sample relative to the deeper sample. However, this pattern does not hold for ^{26}Al and ^{36}Cl.

Although the excess ^{10}Be is only 0.8-1.6 % of the total amount of ^{10}Be in the soil, the result suggests that the excess ^{10}Be is likely etched from the outermost layer of 78481. If 20 % of ^{10}Be in the 0.002 mmol HF fraction of 78481 was implanted ^{10}Be, the excess ^{10}Be is ~2x10^{-5} dpm or 2x10^7 atoms per 200 mg soil 78481. Assuming that the bulk of the excess ^{10}Be in the sampled area remained for the ^{10}Be time period in the layer sampled and that the soil density is 1.5 g/cm^3, the implanted ^{10}Be is ~2x10^8 atoms/cm^2 or 2.5x10^{-6} atoms/s·cm^2 on the surface of the Moon. The ^{10}Be escape rate from the Sun is calculated to be 0.1 atoms/s·cm^2 assuming the ^{10}Be flux varies with the inverse square of distance for the Sun's radius and 1 AU. Using the SW proton flux as 2.5x10^8 /s·cm^2 at 1 AU, the ^{10}Be/H ratio is 1x10^{-14}. Excess ^{14}C in lunar soil, which may be from a similar source, has also been reported [4, 5, 6]. Their values scatter between 2.2-3.5x10^{-14} [6] and 1x10^{-11} ^{14}C/H [7]

Preliminary theoretical estimates suggest that the time-averaged solar flare production is on the order of 0.1 ^{10}Be/s·cm^2 at the surface of the Sun and, if most of this is

ejected in large flares without mixing and loss deeper into the Sun, the escape rate of ^{10}Be could be comparable to the production rate [Lingenfelter and Ramaty, personal communication].

If the surface of lunar grains were homogeneously dissolved, the leaching depth was about 0.4-2 μm based on the volume of material dissolved (about 5%) in the 0.002 mmol HF fractions. Since most of the excess ^{10}Be was found in this fraction, the range of implanted ^{10}Be was less than 0.4 μm (~0.1 mg/cm^2), which corresponds to less than ~10 keV/nucleon.

These preliminary results verify the efficacy of the techniques used to detect solar implanted ^{10}Be. Successfully detection of such ^{10}Be from more detailed experiments will be important contributions to solar physics and the study of the solar atmosphere.

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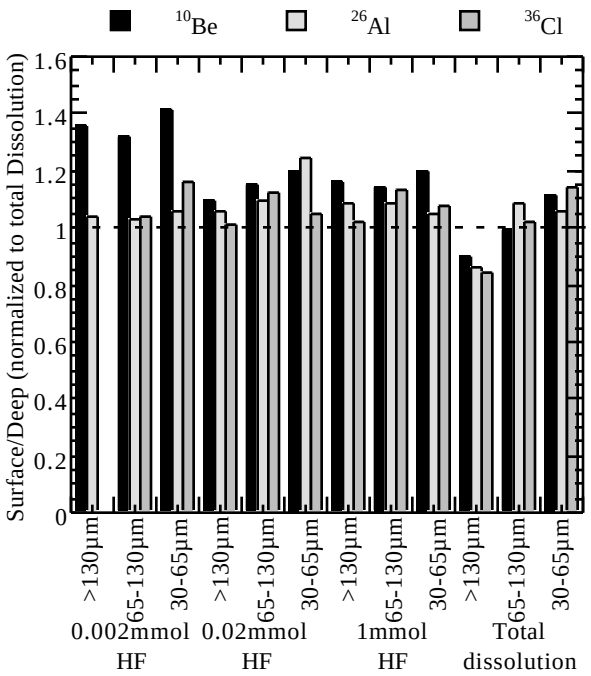

Figure 2. The comparison of radionuclide concentration in surface soils to deep soils. The concentrations were normalized to amount of dissolved materials and concentrations in the total dissolution being to unity.

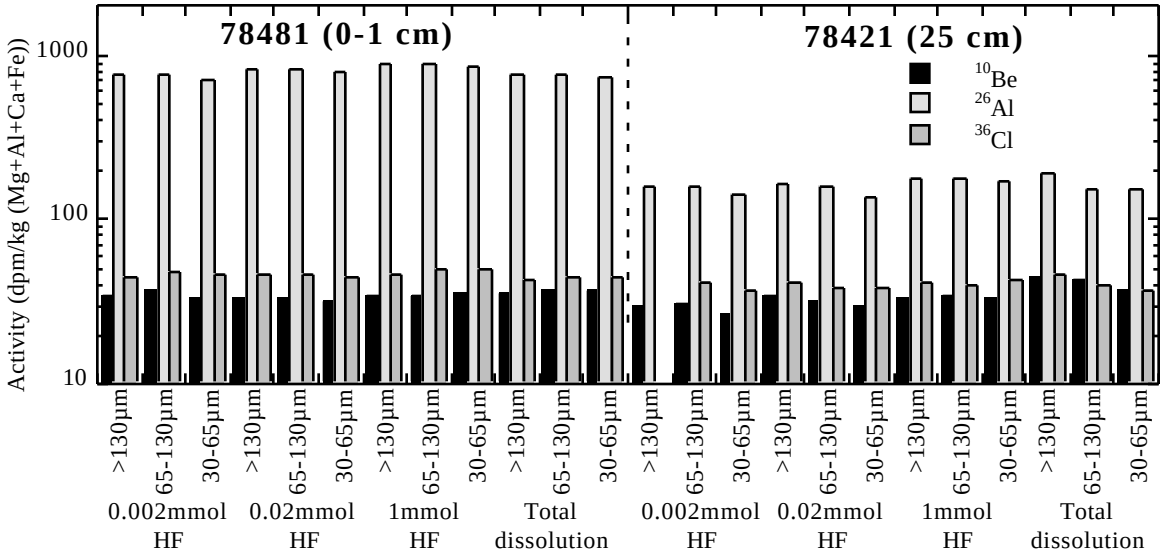

Figure 1. ^{10}Be, ^{26}Al, and ^{36}Cl concentration in stepwise leaching from lunar soil 78481 and 78421. The activity is normalized to the concentration of dissolved Mg, Al, Ca, and Fe.